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PROGRESS REPORT

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## INTRODUCTION

The objective and the approach to be taken in our research participation in the MAGSAT mission are as follows:

### *OBJECTIVE*

The objective of this investigation is to provide experimental and analytical data on the magnetic mineralogy of crustal and upper mantle rock types. These data are necessary to enhance the reliability and interpretation of models of the Earth's deep crustal magnetic anomalies.

### *APPROACH*

The investigator shall pursue the above objective by the experimental determination of mineral stabilities pertinent to magnetic anomaly interpretations, and the determination and cataloging of the magnetic properties of metamorphic rocks of predetermined P-T grade, with similar measurements on mafic and ultramafic suites.

The investigator shall obtain ground truth controls on the susceptibility and Curie temperatures of large suites of samples from a variety of mapped metamorphic grades. This will also include susceptibility and Curie point determinations of mafic suites in varying stages of serpentinization to assess the interactive contributions of oxides, sulfides, and the metal constituents of these rock types.

To this end we have made substantial progress during the report period in three distinct areas related to the magnetic mineralogy of crustal and mantle suites within the sphere of analytical geochemistry and experimental mineralogy. In addition to this we have also completed an integrated analysis of the potential relationship of MAGSAT anomaly data to the geology of West Africa.

Because the nature of our program is multi-faceted and because our proposed research called for a new item of equipment, our progress has not been as rapid on some fronts as it has on others. Nonetheless, the data we have compiled to date are significant, and we are confident these will indeed place the sought after constraints on the interpretation of low amplitude long wavelength magnetic anomalies.

There are a number of tempting and tantalizing interpretations that are possible from the data presented in our progress report. However, we have for the most part abstained from these potential interpretations because the data are incomplete. Where we are confident of the data, insights to their relevancy are briefly described.

#### PROGRESS REPORT

As outlined and discussed in considerable detail in our original MAGSAT proposal, the interpretation of MAGSAT anomaly data depends almost entirely on the nature of the source rocks yielding these anomalies, and hence on the magnetic mineralogy of a variety of petrological types. Because magnetic properties are dependent on the oxidation states of minerals, because we have proposed that metal alloys are alternatives to oxides as potential magnetic carrier minerals, and because a large number of satellite-derived anomalies have possible sources that extend into the lower crust or perhaps even into the upper mantle, it is these aspects that our efforts have been directed towards. These may be briefly summarized as:

(a) An evaluation of the oxidation state of the lower crust and upper mantle, and on whether basalts are adequate probes to the oxidation state of their source regions.

(b) The experimental determination of the phase relationships of minerals and metal alloys in the system defined by the components Fe-Ni-O.

(c) The mineral chemistry of potential magnetic source materials in kimberlites, which can be demonstrated to have originated in the upper mantle.

Our long standing interest in the geology of West Africa prompted a brief analysis of MAGSAT data for that sector of the globe. We consider that the relationship we demonstrate is convincing and that this is a clear endorsement to the usefulness of the data in applications to large scale features for which the ground truth is well established.

A synopsis of the above four mentioned topics are discussed in the section that follows.

#### *OXIDATION PROFILING OF THE CRUST AND MANTLE.*

A graphical treatment of the expected ranges of oxidation as a function of temperature and pressure are illustrated in Figs 1a and 1b. Although these are based on two contrasting sets of experimental data (Woermann *et al.*, 1977; Eggler *et al.*, 1980), the results are remarkably similar, with the profiles illustrated in Fig 1b being the preferred projected state of oxidation with depth. We have included in our plot of Fig 1b the basalt-eclogite transition and the shield and oceanic geotherms. In addition to this we have also calculated and have projected the more common oxygen buffer curves (FMQ and WM) that are applicable to 1 atm. conditions (*i.e.* at the surface of the earth). Because all of the curves are relatively steep, the relative changes in oxidation state with depth do not change dramatically along any one buffer. However, the progressive changes that do apply are along either the shield or oceanic geotherms, and a substantial change in oxidation state does take place with increasing depth.

Now that we have modelled the oxidation state of the crust and the mantle, more meaningful estimates can clearly be made on the stability (or the potential stability) of minerals in any selected regime that is likely to be of magnetic interest, specifically those of a metamorphic nature.

*BASALTS AS OXYGEN PROBES TO THE LOWER CRUST AND UPPER MANTLE.*

As a supplement to the above estimates of the oxidation state at depth we have also compiled and have updated (from Haggerty 1976) temperature and oxygen fugacity data on basalts, on mantle-derived suites, and for the purpose of completeness also data on basaltic achondrites because some of these oxidation states may be pertinent to some regions of the earth's mantle. These data are presented in Figs 2a-2d. On integrating these data with the oxidation profiling that is illustrated in Fig 1b we find that if the depth estimates at which basalts are considered to originate (*i.e.* 20-100 km) are used on Fig 1b, that the levels of oxidation that are preserved in basalts extruded at the surface are comparable to the oxidation levels calculated. A high degree of confidence now exists, therefore, on the probable oxidation state of the lower crust and upper mantle. Hence, as above, we can more confidently predict the likely magnetic mineralogy for any given depth, whether igneous or metamorphic.

*METAL ALLOYS AS POSSIBLE SOURCES OF MAGNETISM.*

As an alternative to having conventional oxides (magnetite, specifically) as the sole source of magnetism in rocks it was earlier suggested that metal-alloys are potential substitutes (Haggerty, 1978). To this end we have undertaken, in a companion study, a set of experiments related to the stability of metal alloys (specifically Fe and Ni) as a function of temperature and oxidation state. A summary of these data, from McMahon and Haggerty (1980), are illustrated

in Fig 3. The significance of the data with respect to MAGSAT and the magnetic mineralogy of crustal or mantle materials is that we have now established the regimes of magnetite and metal alloy stability and can demonstrate that these phases are potential sources of magnetism at depth. Moreover, the data are entirely consistent with those illustrated in Figs 1 and 2.

#### *MAGNETIC SOURCE MINERALS IN THE MANTLE.*

It has been a widely accepted tenet that the mantle and the lower crust are devoid of magnetic minerals, a proposition that is clearly in error when one considers that spinel is a common component. More significant is the fact that minerals other than spinel (e.g. ilmenite), on decomposition, produce magnetite in large concentrations. In an attempt to unravel the mineral chemistries of these breakdown products, and therefore to determine the mechanisms responsible for decomposition, we have undertaken a systematic examination of kimberlitic ilmenites from Liberia (12 localities) and from Sierra Leone (Koidu # 1, 2 and 3 pipes). These data are illustrated in Figs 4a-4e in which many hundreds of electron microprobe analyses are presented. The salient features of these diagrams are: (1) that magnetic spinels develop on decomposition (*i.e.* these minerals have high magnetite components); and (2) that the process of decomposition is related to subsolidus reduction, induced in most cases by high sulfidation activities, but also by carbonation processes. This is a highly significant new result because it demonstrates unequivocally that magnetic minerals are indeed present at depth, a predication that is again borne out by the data presented in Fig 1.

#### *MAGSAT - GEOLOGICAL CORRELATIONS IN WEST AFRICA.*

We have drawn upon extensive field experience in West Africa in presenting the extraordinary correlation that exists between the geological distribution of



rock types in that part of the continent with MAGSAT anomaly maps (Figs 5a-c). The high degrees of correspondence determined are as follows: (1) the Archean (1700-2900 my) metamorphic shield areas of Leo and Reguibat are characterized by negative anomalies (-2 to -6 $\gamma$ ); (2) the prominently developed and intervening sedimentary Paleozoic Taoudeni basin has a positive anomaly (8 $\gamma$  max) and its boundary against the shields is defined by the zero  $\gamma$  contour; (3) negative magnetic anomalies correspond to regional positive gravity anomalies, and the inverse relationship is also present. However, there are no apparent magnetic signatures related to the mobile belts that surround the shield areas. Because of the excellent correlation that exists between the deep rooted shield geology and the MAGSAT anomaly data, and because of the absence of any expression in the mobile belts, we conclude that the anomalies are not merely a surface expression of the geology but a reflection of rock masses that extend to considerable depths into the crust.

#### SUMMARY

Considerable progress has been made in our predictive abilities to evaluate the potential stabilities of magnetic minerals in the crust and mantle by:

- (1) computed oxidation state profiling as a function of temperature and pressure (Fig 1);
- (2) the compilation of data on basalts establishing the validity of (1) as in Fig 2;
- (3) the experimental determination of Fe-Ni alloys in association with magnetite as a function of temperature and oxidation state (Fig 3);
- (4) the acquisition of large chemical data banks on the mineral ilmenite which decomposes to a magnetic spinel in the presence of high sulfur or carbonate environments in the lower crust - upper mantle (Fig 4).

In addition to these data, which are related to constraining Curie isotherm depths, we have also established that an excellent correlation exists between MAGSAT anomaly data and the geology of West Africa.

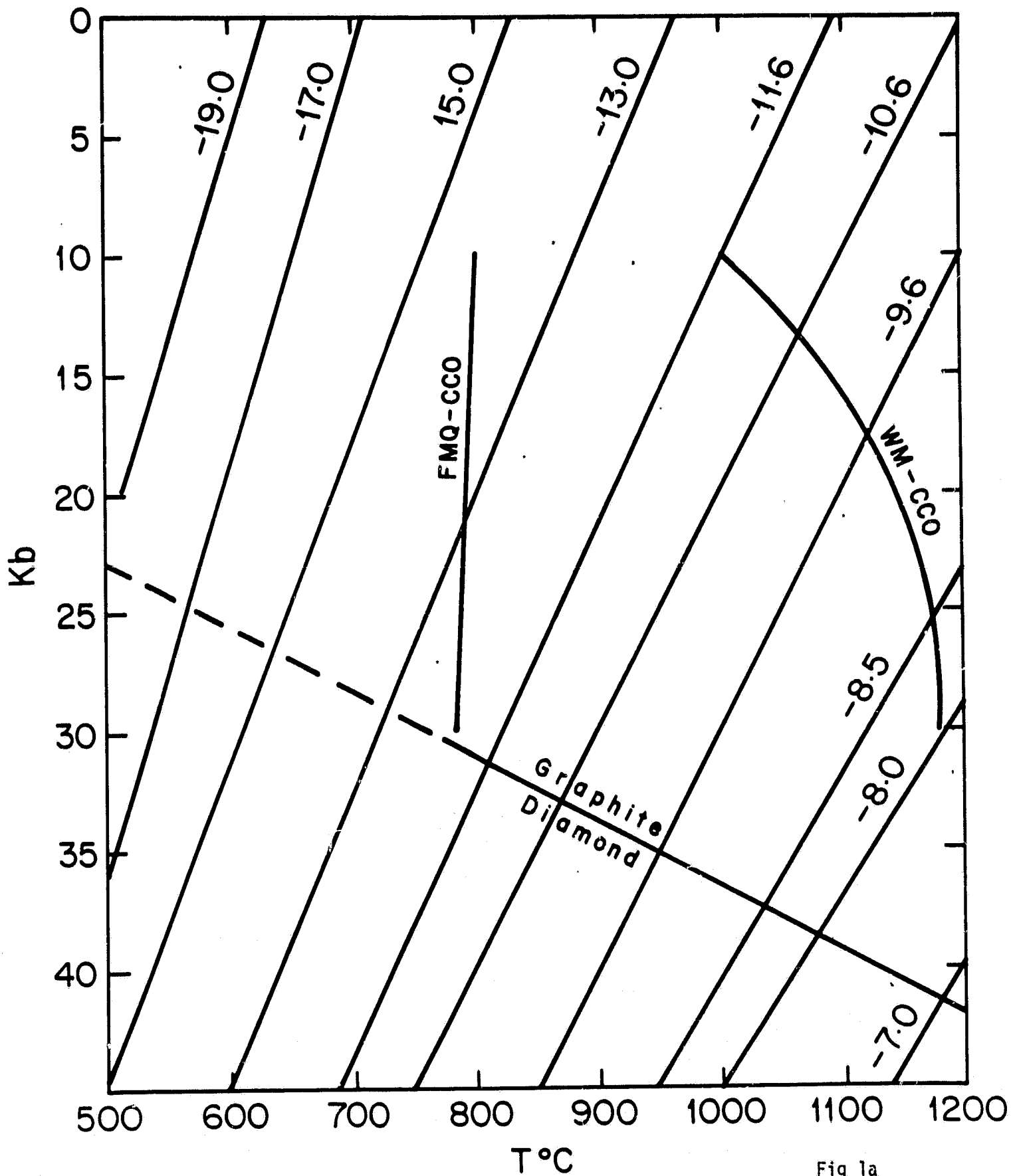


Fig 1a

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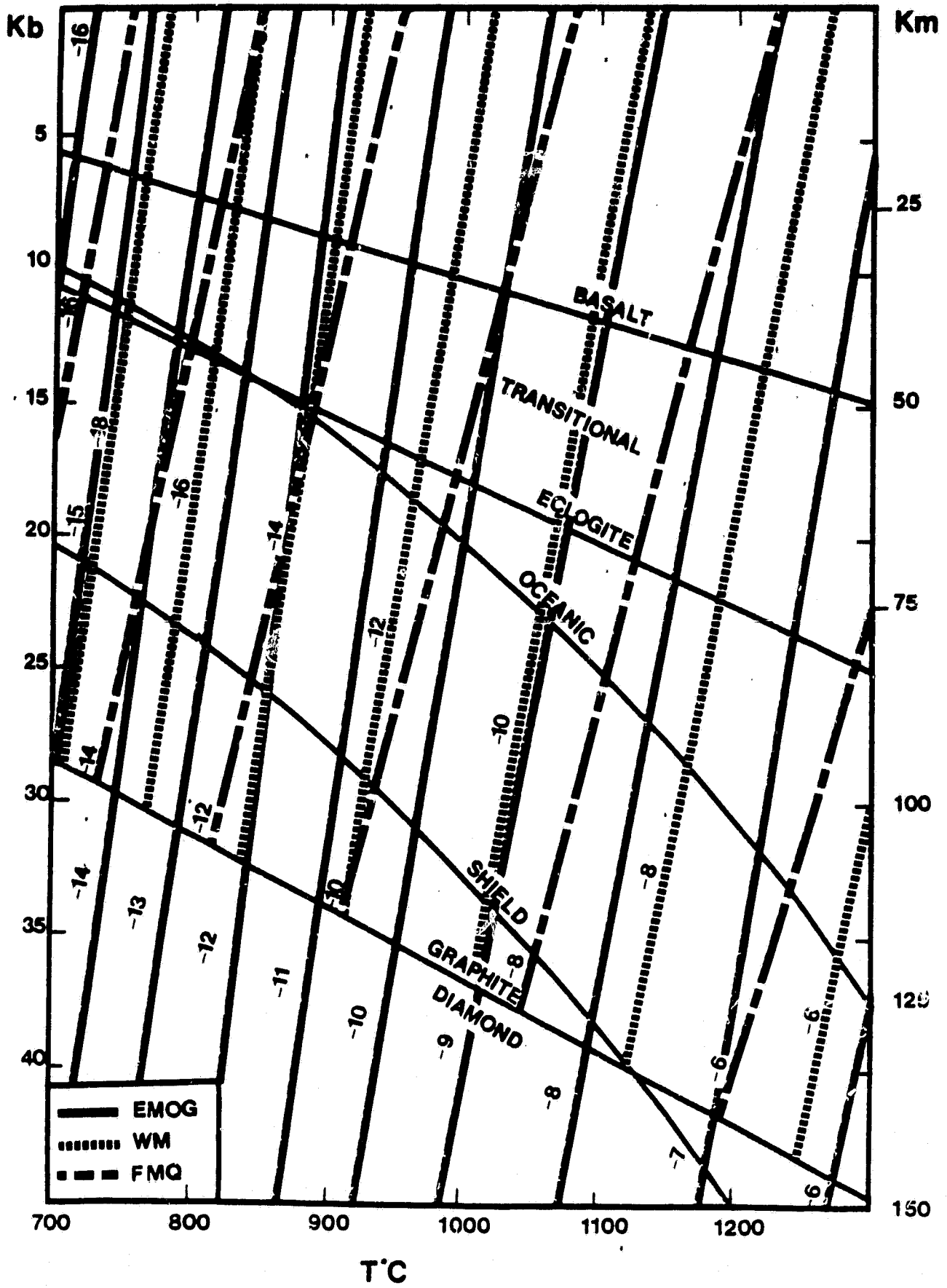


Fig 1b

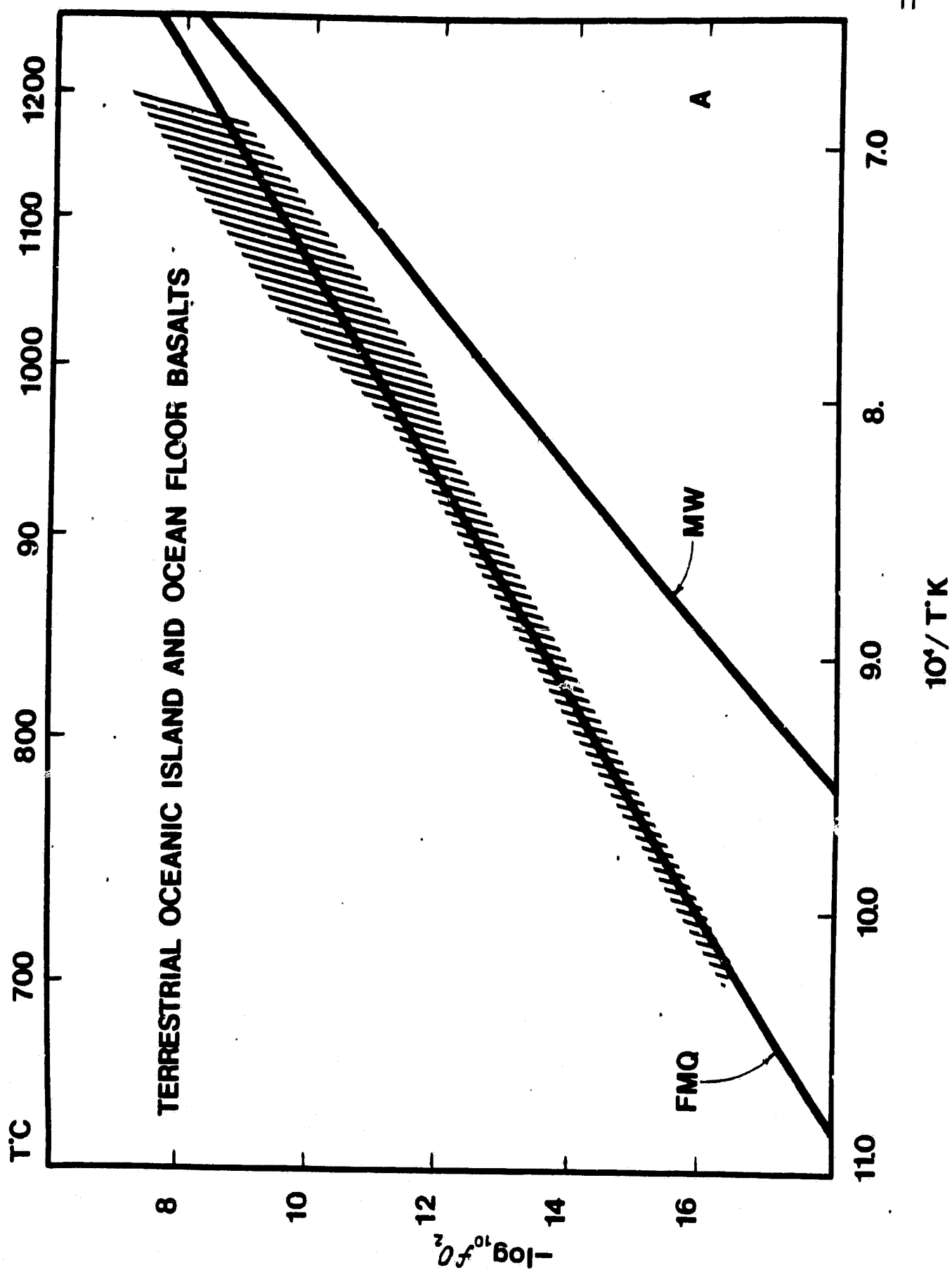
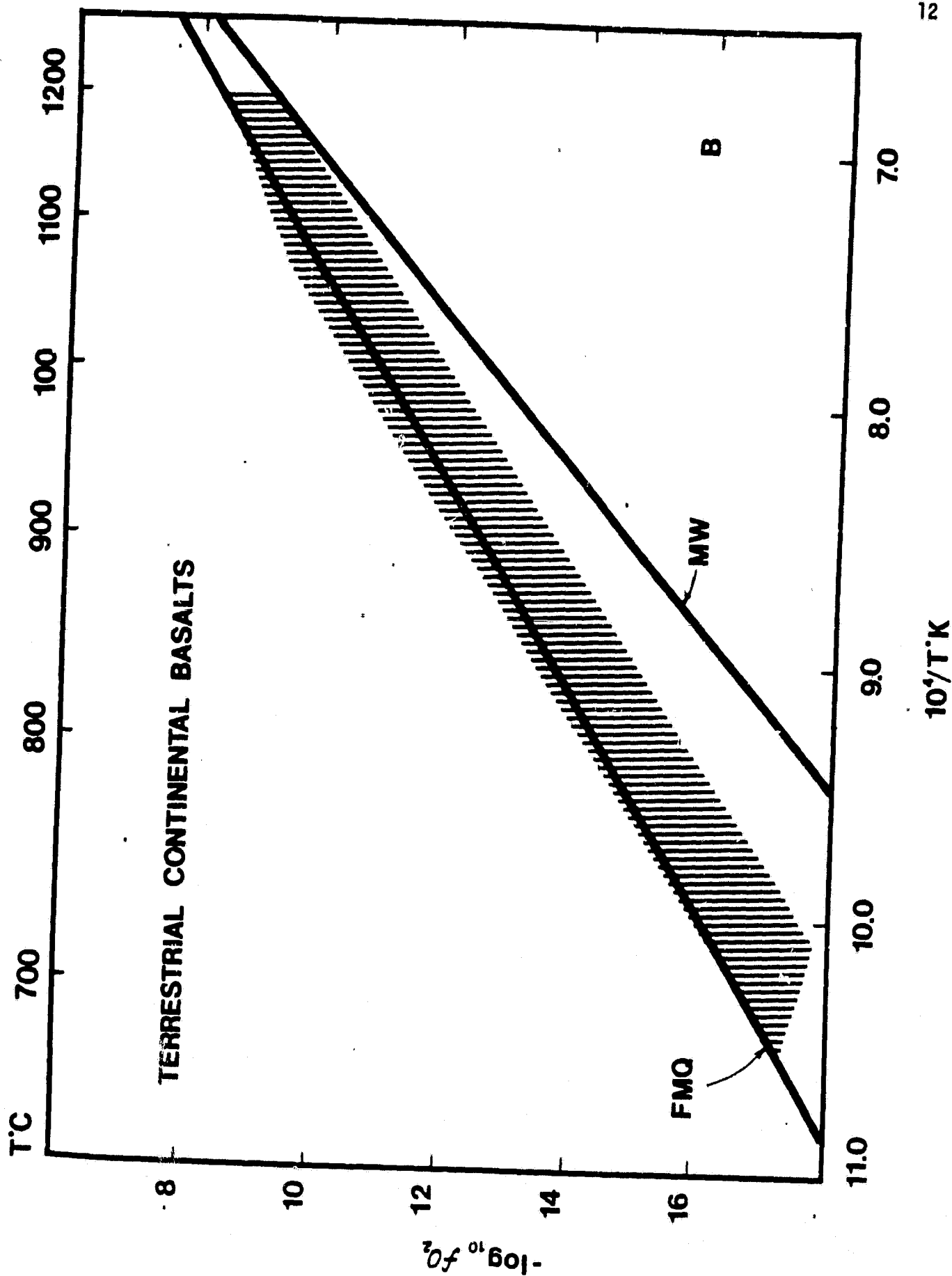


Fig 2a



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Fig 2b

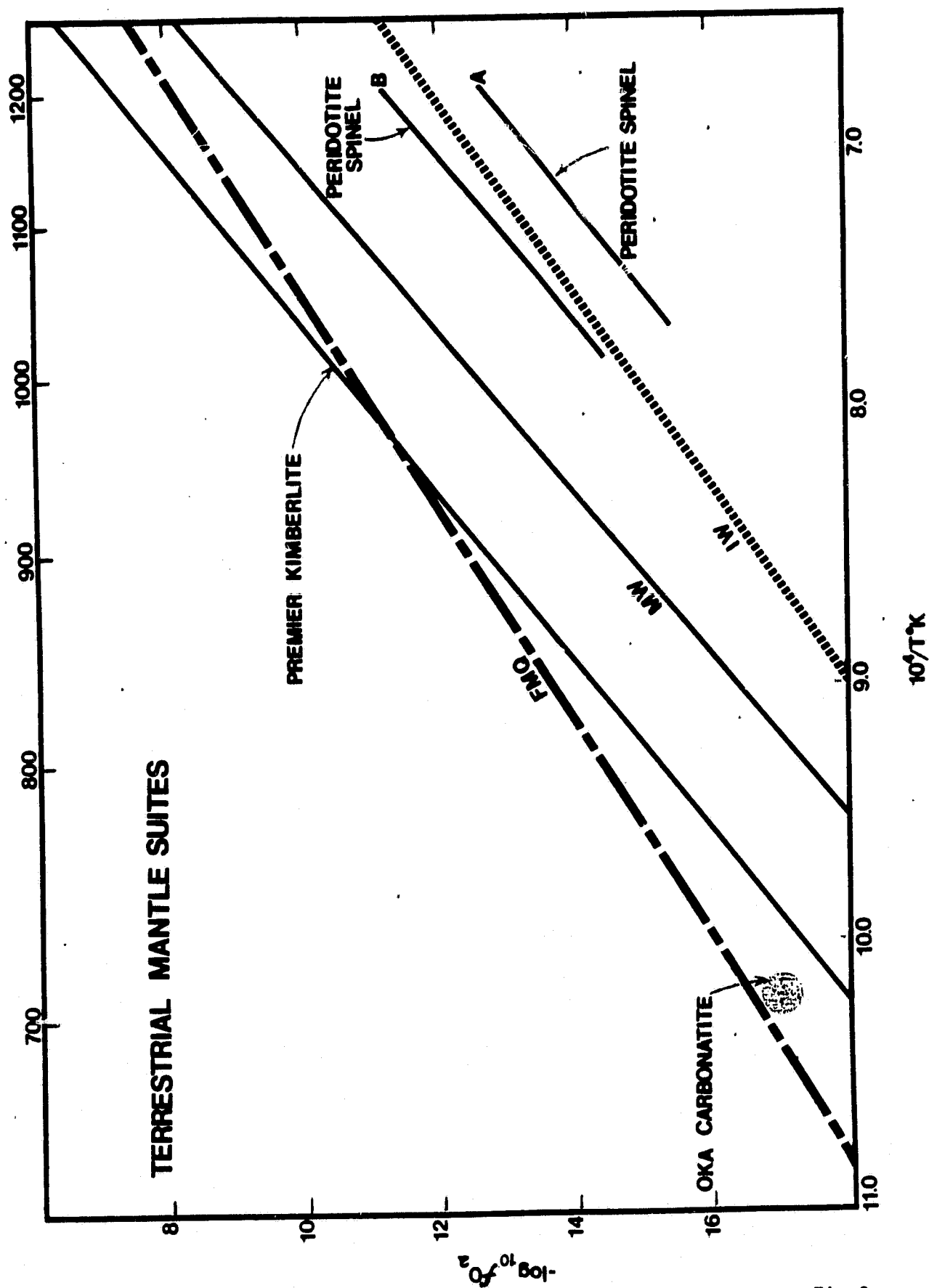


Fig 2c

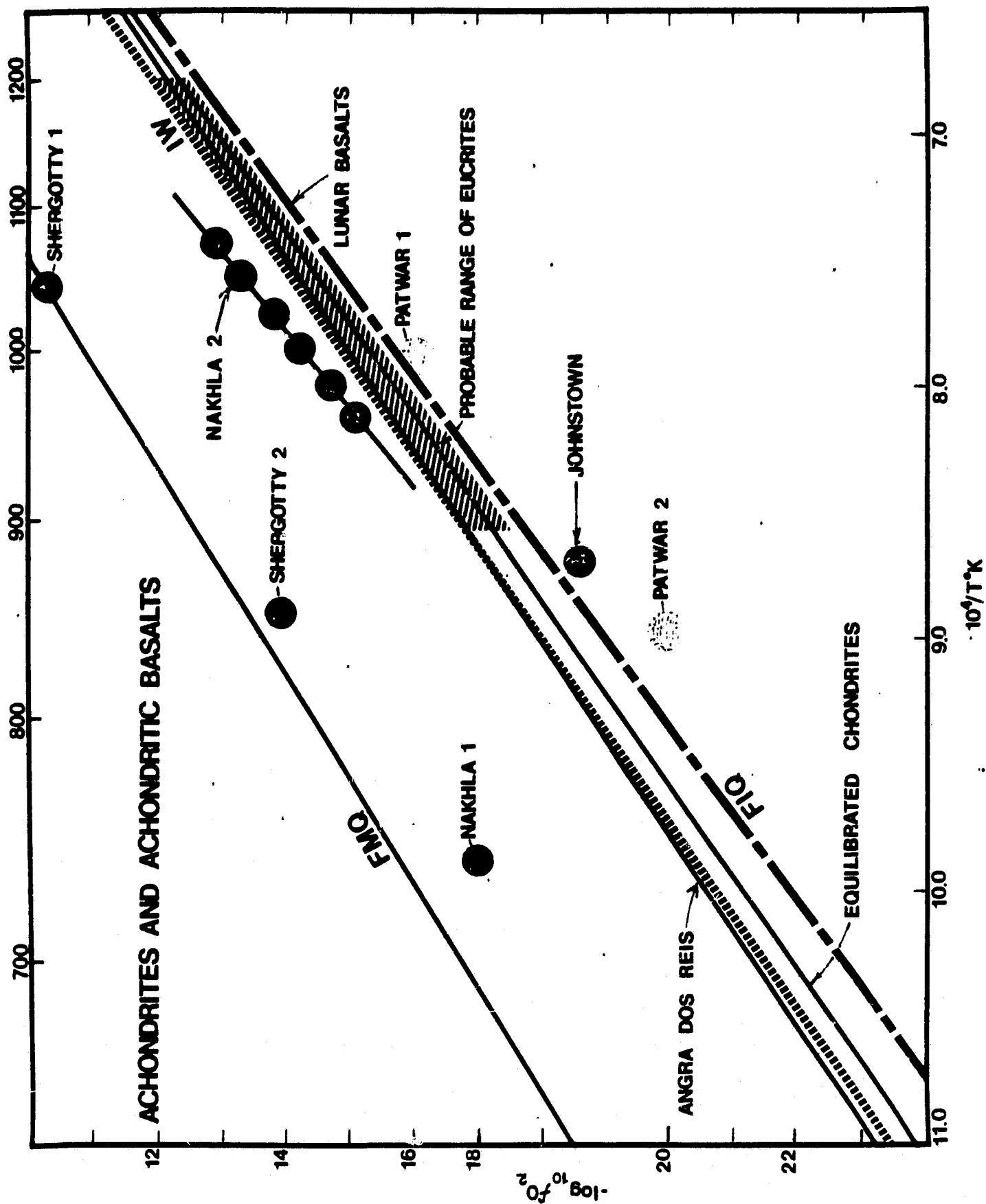


Fig 2d



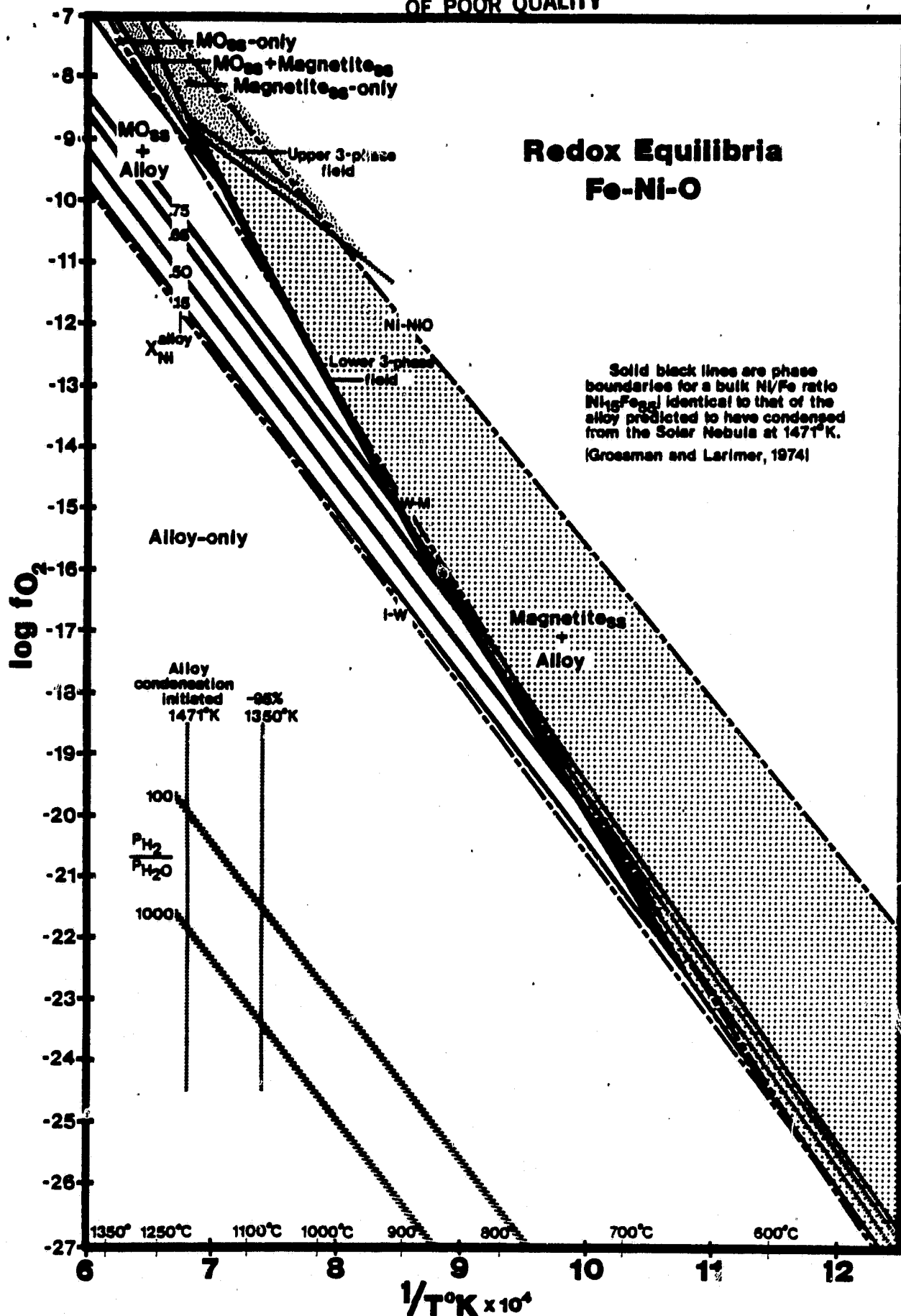


Fig 3

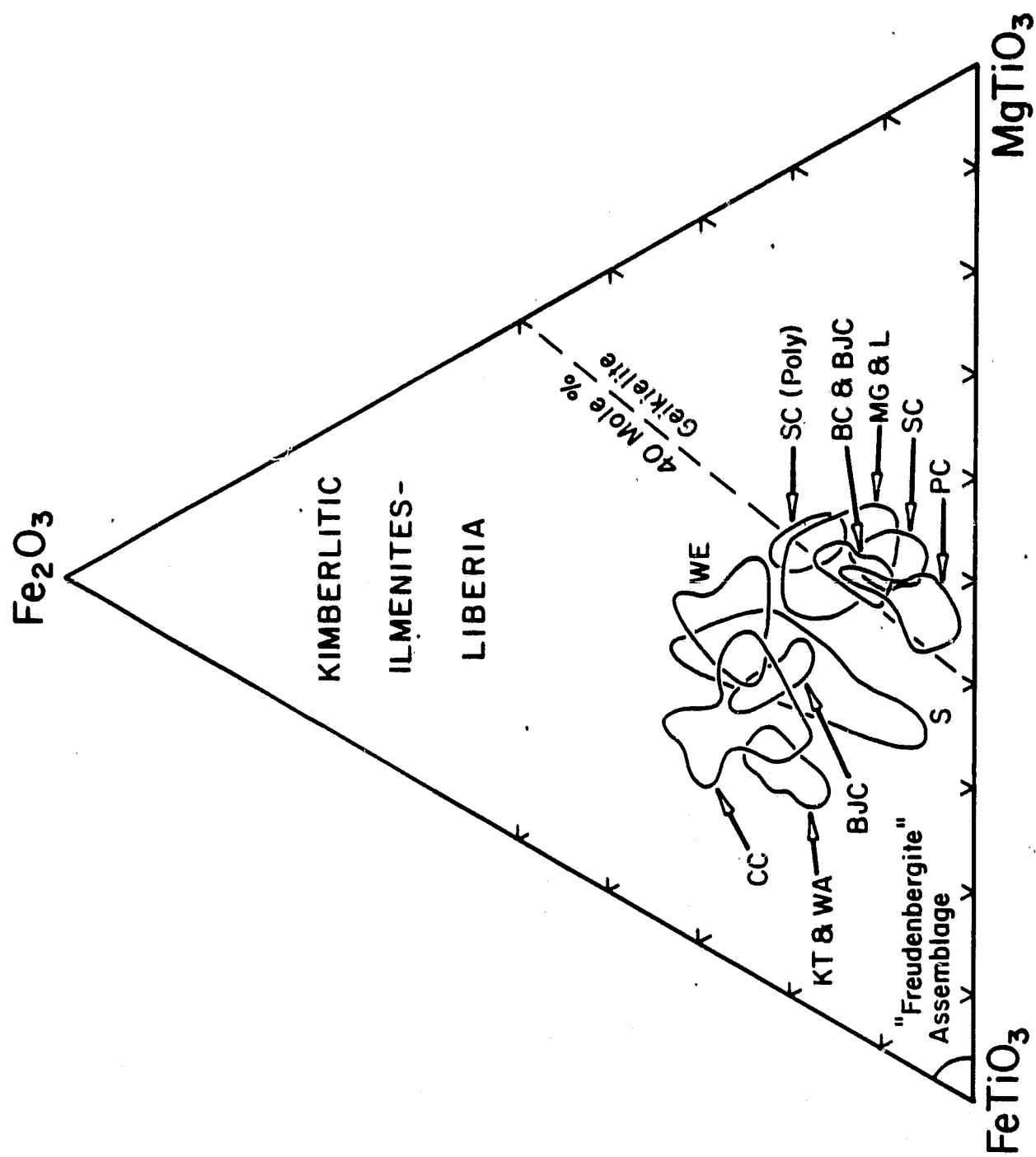


Fig 4a

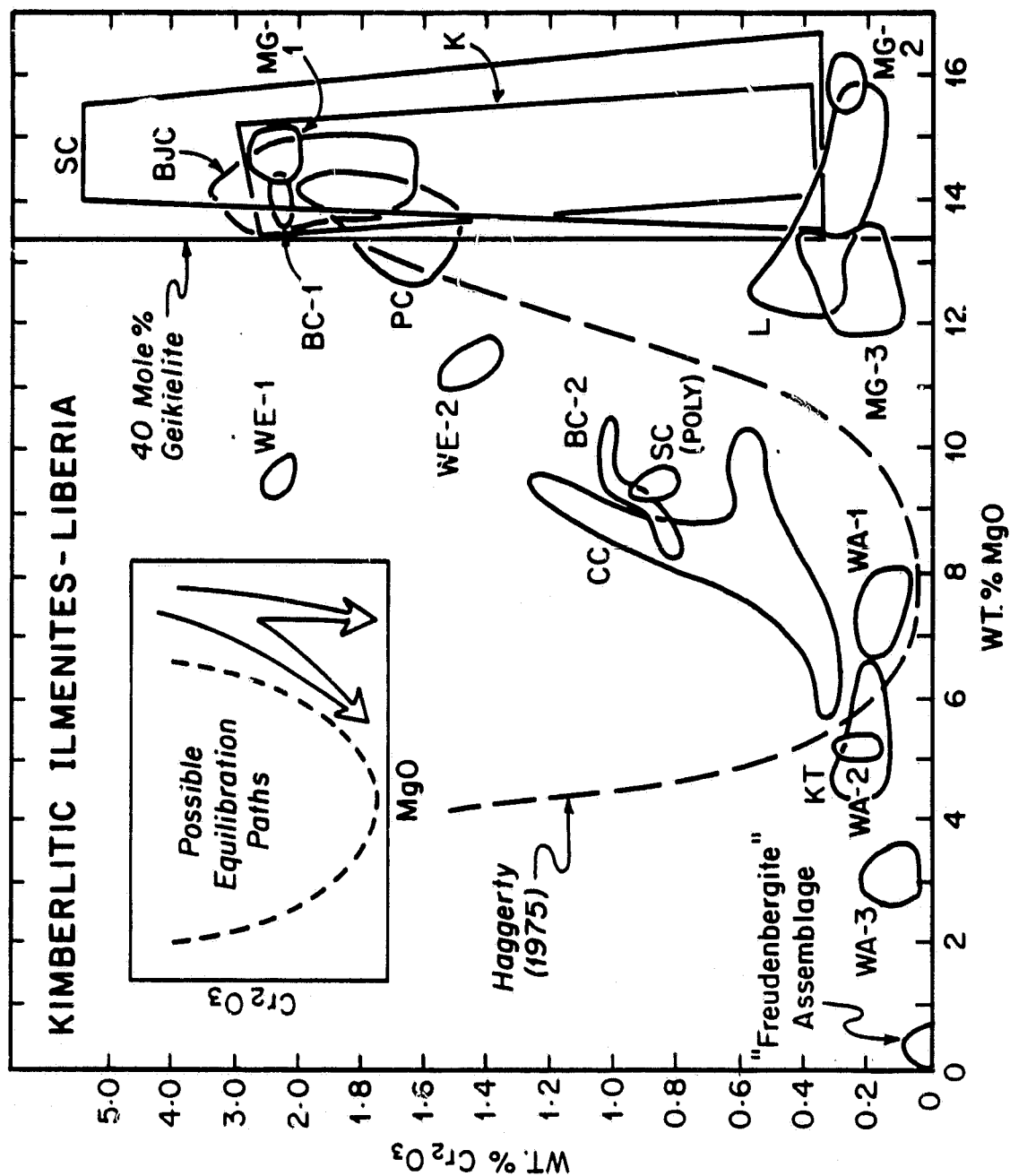


Fig 4b

# KOIDU - ILMENITES

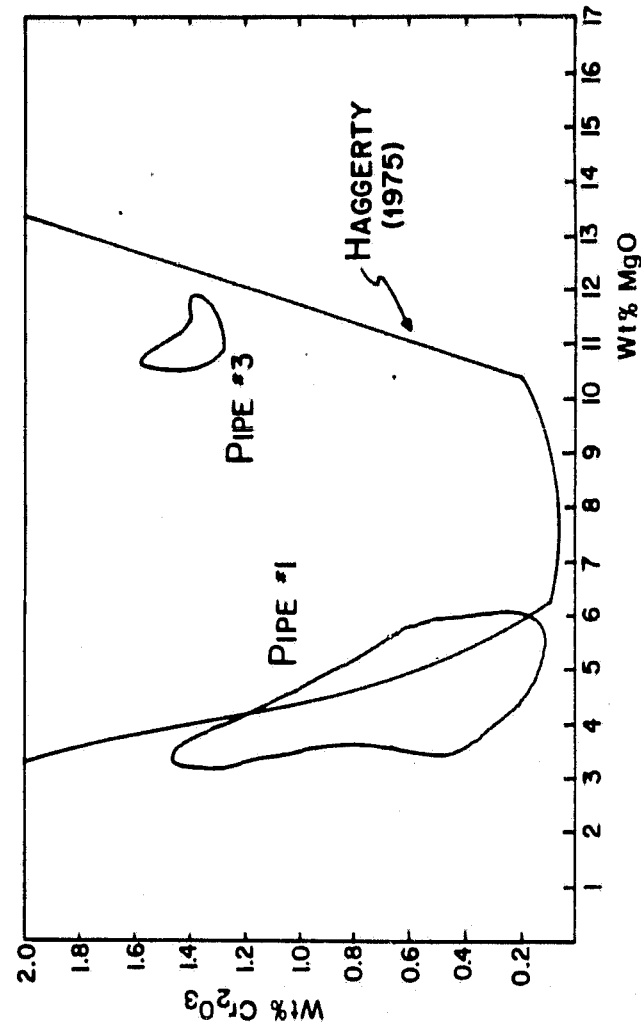
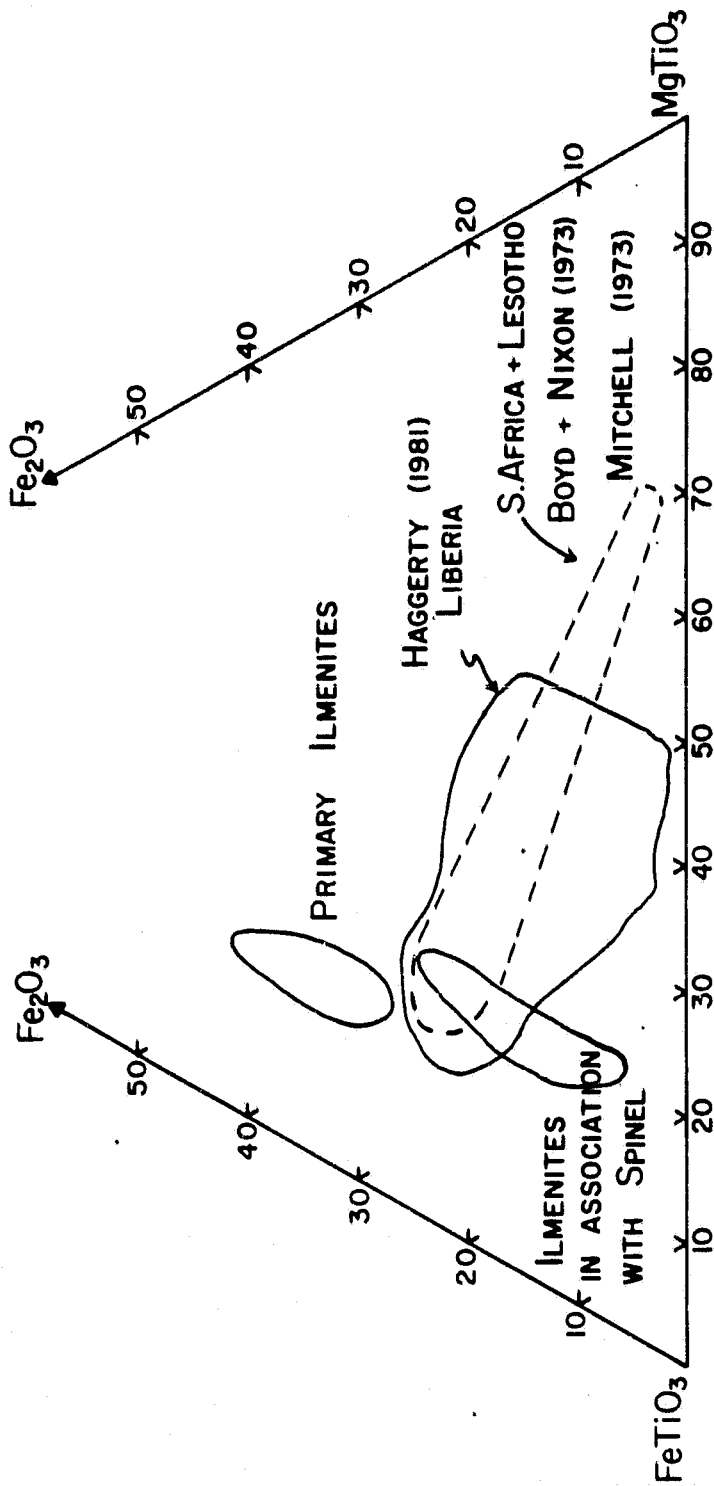


Fig 4c



# KOIDU : ILMENITE-SPINEL RELATIONS

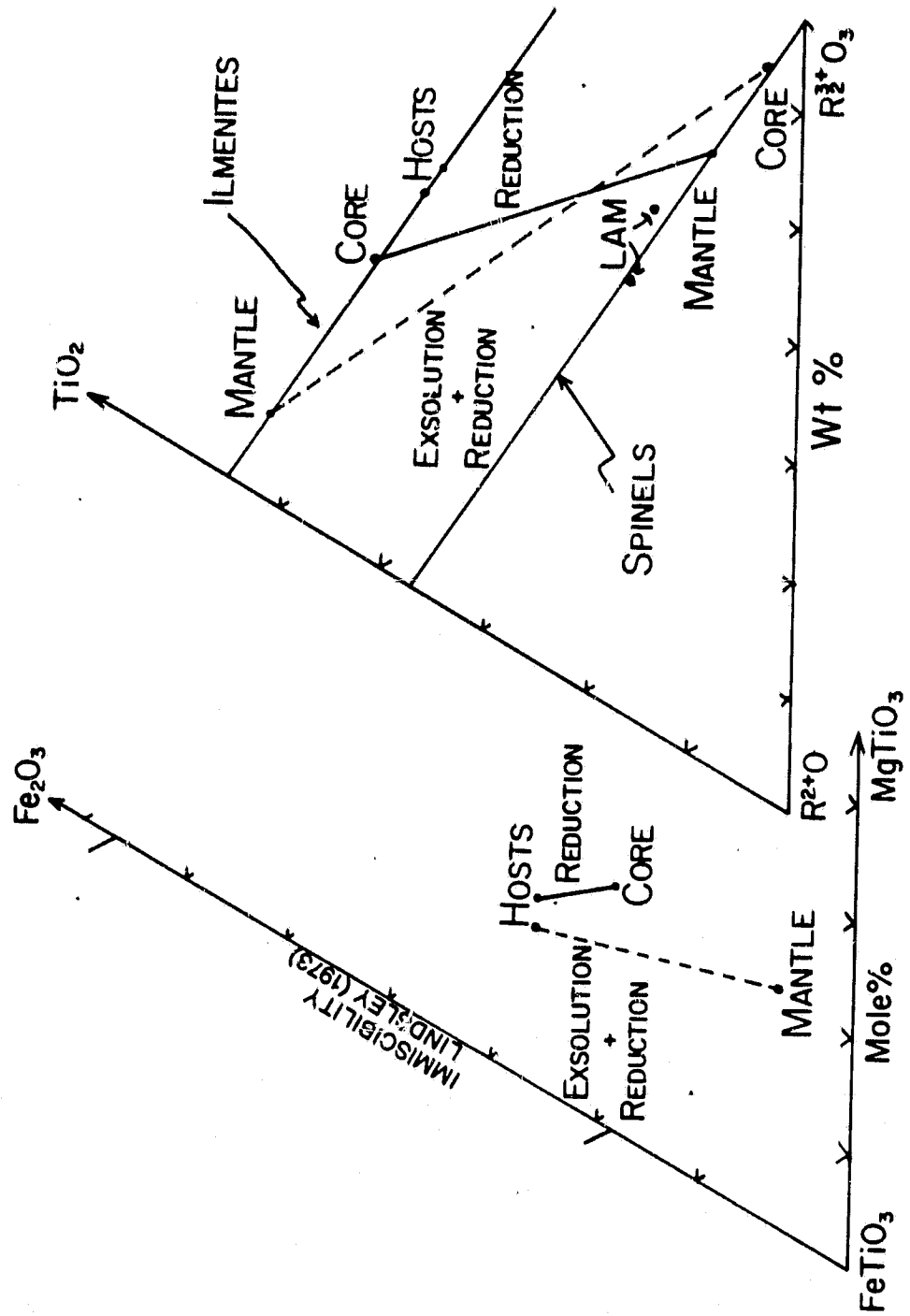


Fig 4e

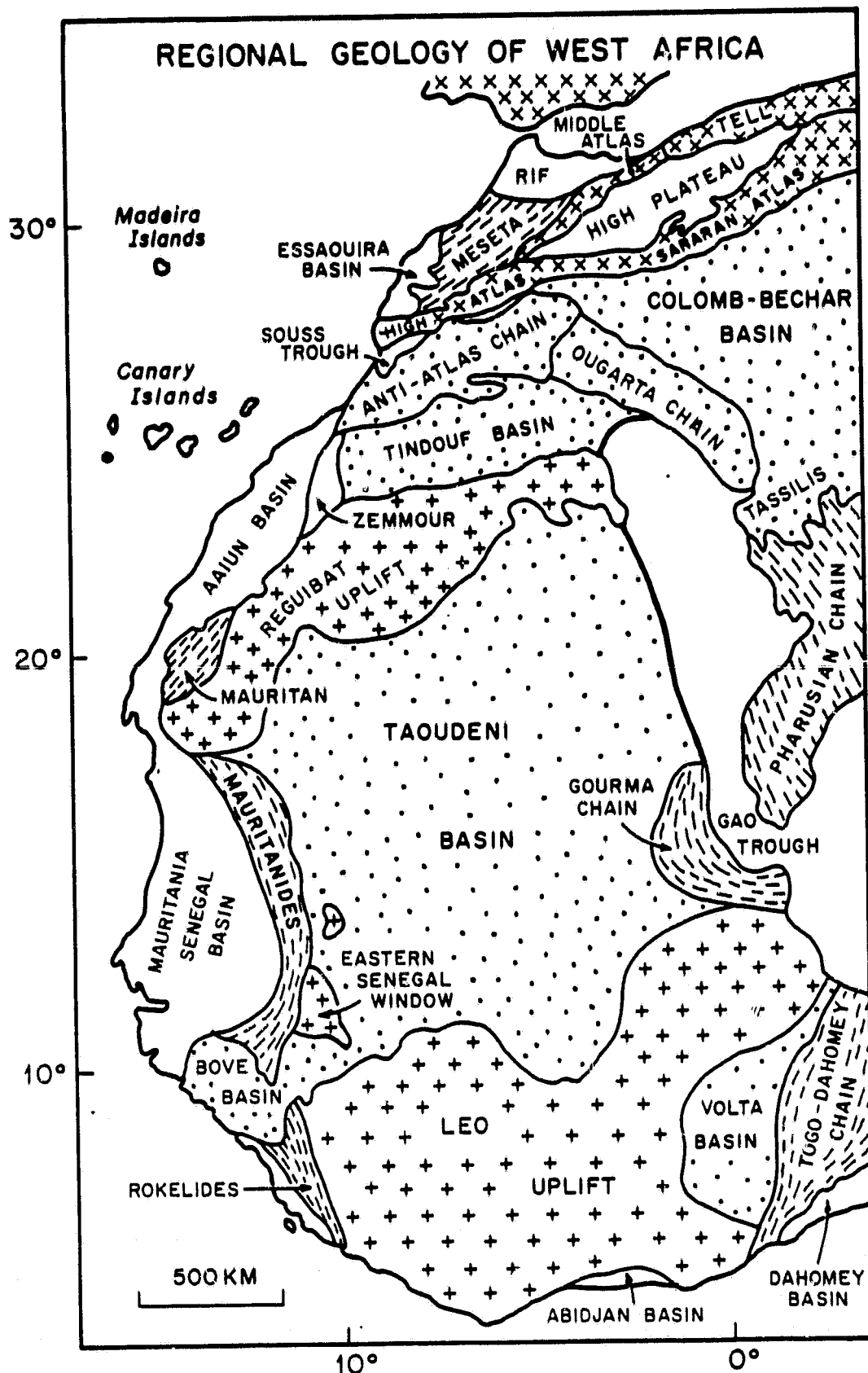


Fig 5a

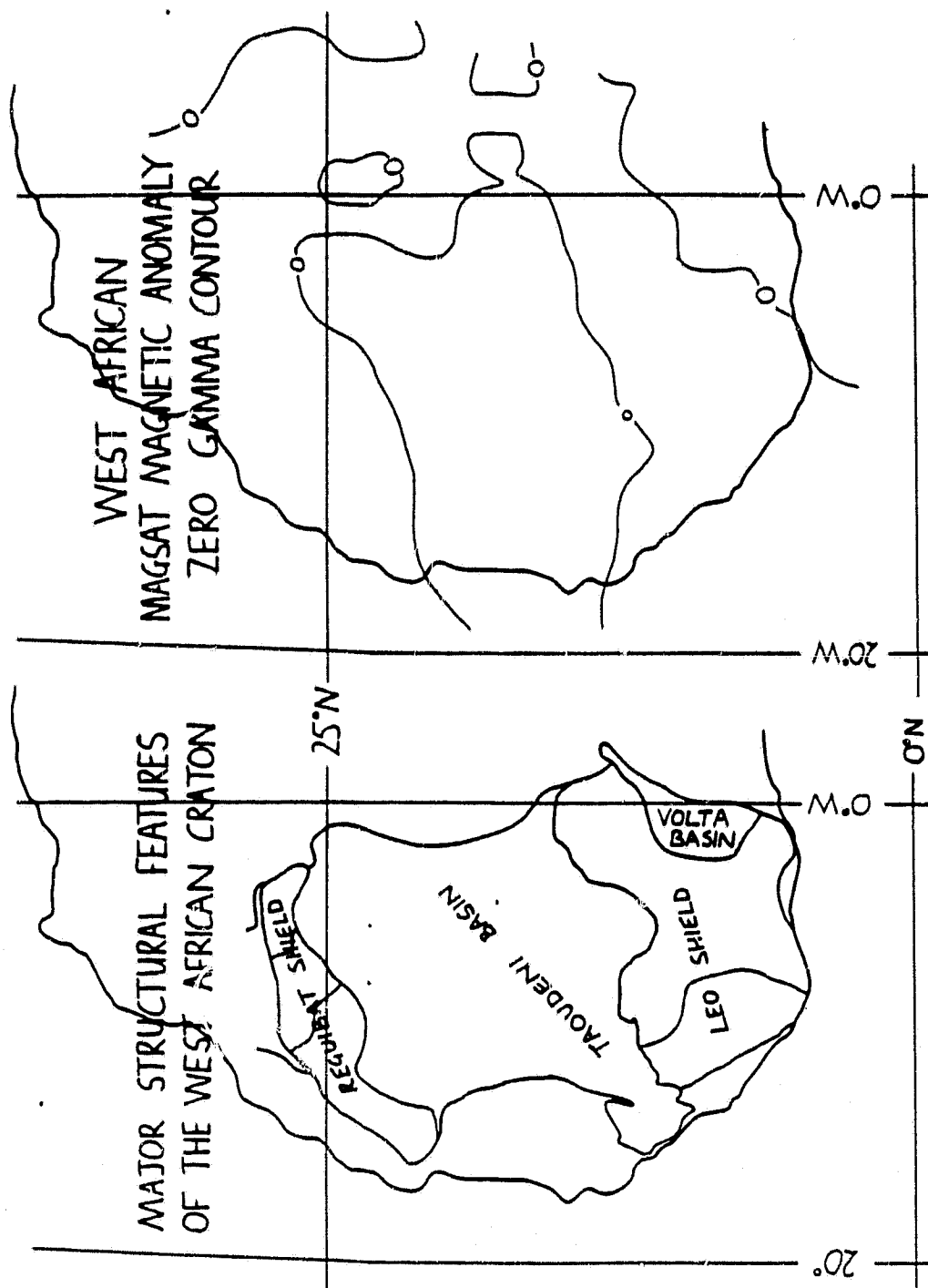


Fig 5b



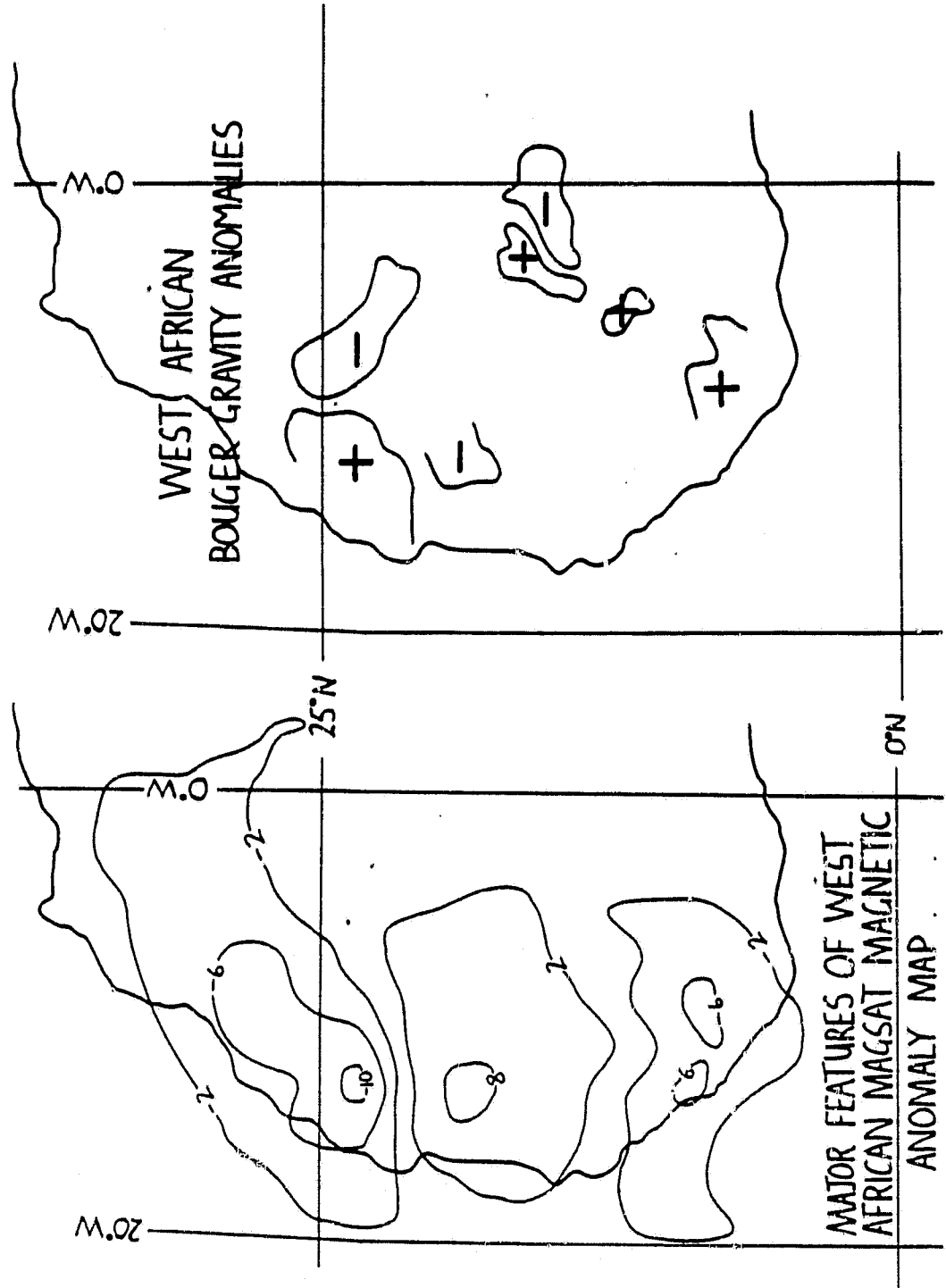


Fig 5c

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## PROBLEMS

One problem only has confronted our planned research program and this has been in the acquisition and in the setting up of our Curie balance and magnetic susceptibility system. After receiving our NASA funding and the approved matching grant from the University of Massachusetts, the order was finally placed on February 4, 1981. The system was delivered on July 1, 1981 but a critical component, namely the high temperature system has yet to arrive. The projected date for final installation has now been set for early to mid-October, 1981.

Although this has prevented our being able to carry out the geochemical and magnetic program simultaneously it has not inhibited our progress to any great extent. We have come much further than expected in our mineralogical program because all efforts have been concentrated in that direction. However, in the absence of magnetic data on our experimental run products or on natural occurring assemblages for which the analytical data are completed, no substantive conclusions or interpretations can yet be made.

## PLANNED RESEARCH

The next stage of our proposed research will be on the magnetic property determinations of a large backlog of materials on which mineral and geochemical data have already been acquired. In the event that our magnetic system is inoperative our experimental and analytical program will continue at an accelerated pace - a substantial number of samples remain to be analyzed using the electron microprobe.

Based on the trans-Atlantic correlations of shield areas that have already been established geologically, the next and logical step that we will undertake

is to determine whether MAGSAT anomaly data are as clearly correlateable in NE South America as is evidently the case in West Africa. We note that these correlation exercises are on a no-cost basis to NASA.